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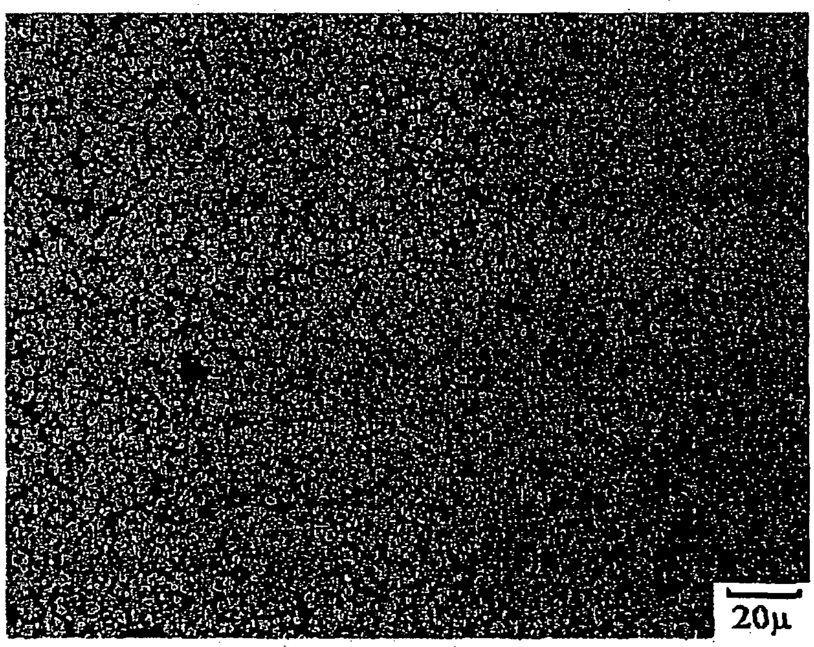

(57) Abstract: A metal flow system is provided for use in pressure casting of an alloy, using a pressure casting machine having a source of supply of molten alloy. The system includes a mould or die tool component which defines at least part of a flow path into which molten alloy is receivable from the source of supply and along which alloy is able to flow for injection into a die cavity defined by a mould or die. The mould or die tool component defines, as part of the flow path, a controlled expansion port (a CEP) which, from an inlet end to an outlet end of the CEP, increases in cross-sectional area whereby the state of alloy in its flow through the CEP is able to be modified from a molten state to achieve a semi-solid state possessing thixotropic properties and to enable the alloy in that state to flow into the die cavity. The CEP has a form such that, with solidification of alloy in the die cavity and back along the flow path into the CEP, to provide a resultant casting having a microstructure characterised by fine, degenerate dendrite, or spheroidal or rounded, primary particles in a matrix of secondary phase, alloy solidified in the CEP has microstructure characterised by striations or bands extending transversely with respect to the alloy flow therethrough, with the bands resulting from alloy element separation, and with alternate bands relatively richer in respective elements and respectively in primary and secondary phases.

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METAL FLOW SYSTEM

This invention relates to a metal flow system for use in high pressure casting of alloys, and to a process and apparatus for use in high-pressure casting using the metal flow system.

In earlier work, disclosed in PCT/AU98/00987 (WO99/28065) filed on 30 November 1998, in PCT/AU01/00595 filed on 22 May 2001, in PCT/AU01/01058 filed on 25 August 2001 and in PCT/AU01/01290 filed on 12 October 2001, we have disclosed developments in relation to the high pressure casting of alloys. PCT/AU98/0987 relates to such casting of magnesium alloys, PCT/AU01/01058 relates to such casting of aluminium alloys, while PCT/AU01/00595 and PCT/AU01/01290 relate to devices for use in casting those and other alloys such as, but not limited to, zinc and copper alloys.

A feature of that earlier work is the provision and use of what, in PCT/AU98/00987, is referred to as a controlled expansion region and, in the other applications, as a controlled expansion port, abbreviated to "CEP". The latter term will be used herein, although the controlled expansion region and a CEP designate the same feature. This is a relatively short length of an alloy flow path, defined by part of a mould assembly or by an insert in such assembly, which provides required flow of alloy into a die cavity or each of a plurality of die cavities, of the mould assembly.

A CEP, while relatively short, is a part of an alloy flow path which increases in cross-section from an inlet end of the CEP and through to an outlet end of the CEP. At the outlet end, the CEP may open to or within a die cavity, in an arrangement providing for casting by direct injection. While the outlet end preferably opens to the die cavity, there are circumstances where the form of the die cavity, in a region into which alloy first flows, is such that the region of the die cavity is able to define at least an outlet end portion of the length of the CEP. That is, the CEP may be at least in part within, and defined by, the region of the die cavity.

In an alternative to such direct injection arrangement, alloy may flow through a sprue region to a runner. In that alternative, a CEP may be provided at the inlet or outlet end of the runner, or between respective runners. A runner which provides alloy flow to the CEP has a cross-sectional area which is

not less, and preferably is greater, than the cross-sectional area of the inlet end of the CEP. Similarly, a runner which provides alloy flow from the CEP has a cross-sectional area which is not less, and preferably is greater, than the cross-sectional area of the outlet end of the CEP. In each case, the arrangement is to ensure efficient working of the alloy flow system in terms of die cavity fill.

In the variants of that alternative to the direct injection arrangement, there may be a plurality of runners each receiving a respective portion of alloy flow from the sprue region. Each of the runners may provide alloy flow to a common die cavity or to a respective die cavity. With use of a plurality of runners, there may be a single CEP through which alloy flows to each runner, with the runners having an aggregate cross-section downstream of the single CEP which does not provide a significant constriction to the flow of the portion of the alloy received from the CEP to the or the respective die cavity. Alternatively, there may be a respective CEP for each of the plurality of runners, with each runner preferably having a cross-section in its extent from the outlet end of its CEP to its die cavity which is not less than the cross-section of that outlet end.

In a direct injection arrangement, the flow of alloy to the die cavity may continue along an initial flow direction. However, where a runner arrangement is provided for indirect injection, the or each runner most conveniently extends laterally with respect of that direction. Thus, the runner or runners may extend along a parting plane between separable parts of a die tool which defines the or each die cavity.

With use of a CEP, the state of an alloy in its flow therethrough is able to be modified. Thus, a CEP is able to modify the state of molten alloy to a semi-solid state possessing thixotropic properties during flow through the CEP, and that semi-solid state is able to be maintained into the or each die cavity. For the state of molten alloy to be changed to achieve a semi-solid state possessing thixotropic properties, it is highly desirable that the alloy have a flow velocity at the inlet end of the CEP which is close to or within a preferred range. The range varies, depending on the alloy in question. For a magnesium alloy the CEP inlet end flow velocity may be in excess of 60 m/s, such as from 140 to 165 m/s. For an aluminium alloy, the CEP inlet end flow velocity preferably is in excess of 40 m/s, preferably in excess of 50 m/s, such as from 80 to 120 m/s,

preferably 80 to 110 m/s. For other alloys capable of being converted from a molten state to a semi-solid state having thixotropic properties, such as zinc and copper alloys, the preferred range may be somewhat similar to that indicated for aluminium alloys, although the range can vary with the unique characteristics of individual alloys. In addition to the indicated highly desirable alloy flow velocities at the inlet end of the CEP, the CEP is to achieve a reduction in flow velocity for alloy flowing therethrough. The reduction in flow velocity for magnesium, aluminium and other alloys most preferably is such as to achieve an alloy flow velocity at the outlet end of the CEP which is from about 50% to 80%, such as from 65% to 75%, of the flow velocity at the inlet end.

The form of a CEP, beyond the requirement that it increases in cross-section from its inlet end to its outlet end, can vary substantially. Depending on the size of the casting being made, the length of a CEP can be from about 5 to about 40 mm, such as from 5 to 20 mm and preferably about 10 to 15 mm. Over such short length, the CEP may be of circular cross-section. However, particularly where it opens to a die cavity or is at least in part defined by and within a die cavity, other cross-sections such as rectangular can be used. A CEP may have an axis or centre line which is straight. However, a CEP can, if required, have an arcuate or bent axis or centre line, such that it provides a change in direction of alloy flow therethrough.

The dimensions and form of a CEP can vary in accordance with a number of variables. These include the size of castings being made; the type, size and power of the machine being used; the alloy being cast; the location at which alloy flows into the die cavity, and whether or not at least a portion of the CEP is defined by a region of the die cavity; and the microstructure being sought in the article being cast.

These variables make it difficult to determine the suitable form for a CEP for a given casting to be made. The present invention is directed to providing a basis for determining the form of a CEP.

Under appropriate conditions, it is found that a CEP can provide a casting which, for at least some purposes, has an optimum microstructure substantially throughout the casting. This microstructure is one characterised by fine degenerate dendrite, or rounded or spheroidal, primary particles in a matrix of secondary phase, with the primary particles less than 40 μm, such as

about 10 μm or less. That is, not only is the CEP able to achieve alloy having a semi-solid state in its flow therethrough, in which the alloy possesses thixotropic properties, but it also is able to maintain that state and those properties in the alloy substantially throughout flow of the alloy to fill the die cavity. For at least some forms of CEP able to achieve this, using a die mould providing for sufficiently rapid solidification of alloy therein, we have found that solidification of the alloy is able to progress back into the CEP such that alloy solidified in the CEP has a specific microstructure. While not necessarily definitive of all suitable forms for a CEP, attainment of that specific microstructure is one basis on which the overall requirements for a CEP can be quantified, at least where the indicated optimum casting microstructure for some applications is required or acceptable. However, this discovery is not limited to applications where that casting microstructure is required or acceptable since, as detailed herein, it is a microstructure able to be modified by heat treatment, if this is required for other applications.

The specific microstructure for a CEP is one exhibiting striations or bands which extend transversely with respect to the direction of alloy flow through the CEP and which result from alloy element separation. A CEP able to achieve such microstructure is one capable of generating intense pressure waves in the alloy in its flow through the CEP. The bands, which may extend laterally across substantially the full width of the CEP and which may be spaced along substantially its full length, are found to have a wavelength of the order of 40 μm for a magnesium alloy, and of the order of 200 μm for aluminium and other alloys. Also, the separation of elements is found to result in substantial separation of primary and secondary phases, with the primary phase present as fine, rounded or spheroidal, or degenerate dendrite, particles substantially less than 40 μm in size, such as about 10 μm or less. Thus, for example, with a magnesium alloy having aluminium as its principal alloy element, such as the alloy AZ91D, it is found that alternate striations or bands are respectively aluminium-rich and magnesium-rich, due to separation of the more dense aluminium and less dense magnesium. The magnesium-rich bands are relatively richer in primary phase, present as fine, rounded or spheroidal, or degenerate dendrite, particles substantially less than 40 μm in size, such as

about 10 μm or less. In contrast, the aluminium-rich bands are found to be richer in secondary phase intermetallic particles, such as $Mg_{17}Al_{12}$.

Thus, according to the invention, there is provided a metal flow system, for use in pressure casting of an alloy, using a pressure casting machine having a source of supply of molten alloy, wherein the system includes a mould or die tool component which defines at least part of a flow path into which molten alloy is receivable from the source of supply and along which alloy is able to flow for injection into a die cavity defined by a mould or die; the mould or die tool component defines, as part of the flow path, a controlled expansion port (a CEP) which, from an inlet end to an outlet end of the CEP, increases in cross-sectional area whereby the state of alloy in its flow through the CEP is able to be modified from a molten state to achieve a semi-solid state possessing thixotropic properties and to enable the alloy in that state to flow into the die cavity; and wherein the CEP has a form such that, with solidification of alloy in the die cavity and back along the flow path into the CEP, to provide a resultant casting having a microstructure characterised by fine, degenerate dendrite, or rounded or spheroidal, primary particles in a matrix of secondary phase, alloy solidified in the CEP has a microstructure characterised by striations or bands extending transversely with respect to the alloy flow therethrough, with the bands resulting from alloy element separation, and with alternate bands relatively richer in respective elements and respectively in primary and secondary phases.

The invention also provides a process for producing an article by high pressure casting, wherein molten alloy is supplied under pressure to metal flow system for flow along a flow path defined by the system to a die cavity defined by a mould or die; the flow path is defined at least in part by a mould or die tool component; and wherein the component is formed to define, as part of the flow path, a controlled expansion point (a CEP) which, from an inlet end to an outlet end of the CEP, increases in cross-sectional area whereby the state of the alloy in its flow through the CEP is modified from a molten state to achieve a semi-solid state possessing thixotropic properties and to cause the alloy to flow in that state into the die cavity; the form of the CEP being provided such that, with solidification of the alloy in the die cavity and back along the flow path into the CEP, to provide a resultant casting having a microstructure characterised by

fine, degenerate dendrite, or rounded or spheroidal, primary particles in a matrix of secondary phase, alloy solidified in the CEP has a microstructure characterised by striations or bands extending transversely with respect to alloy flow therethrough, with the bands resulting from alloy element separation, and with alternate bands relatively richer in respective elements and respectively in primary and secondary phases.

The system and process are to be such that, if solidification of alloy in the die cavity is sufficiently rapid, the respective microstructures for the casting and for alloy solidified in the CEP are obtained. Such rapid solidification most preferably is achieved in use of the invention. However, in addition to the need for heat energy extraction from the mould or die to achieve this it can be necessary to control the temperature of the component defining the CEP such that alloy in the CEP is able to be solidified. Most conveniently, heat energy extraction is limited up-stream of the inlet end of the CEP, to enable a solid-liquid interface to be established at, or a short distance downstream from, the inlet end of the CEP.

The pressure casting machine with which the metal flow system of the invention is used can be of a variety of different forms. It may, for example, be a high pressure die casting machine having a nozzle or shot sleeve from which alloy is able to be injected into the metal flow system, for flow along the flow path of the system and through the CEP of the flow path, to the die cavity. Thus, the machine may be a hot- or cold-chamber die casting machine.

Particularly where a cold-chamber die casting machine is used, larger primary particles can form in the shot sleeve and these can be carried through into a casting. Generally the volume fraction of such larger primary particles is low, although the particles can range in size from 60 μm up to 100 μm.

In a further alternative, the machine may be of the type disclosed in our Australian provisional application PR7216 filed on 23 August 2001 entitled "Apparatus for Pressure Casting, in its associated Australian complete application AU-29303/02 filed 28 March 2002 and in an International (PCT) patent application (attorney reference IRN 675225) filed simultaneously with the present application. The disclosures of that provisional application PR7216, complete application AU-29303/02 and PCT application are incorporated herein by reference, and are to be read as forming part of the disclosure of the present

invention. In those disclosures of our provisional application PR7216, and its complete and PCT applications, there is provided a molten alloy transfer vessel having a capacity for holding a measured volume of alloy required for transfer to a die tool and sufficient to produce a given casting, or for simultaneously producing a plurality of given castings which usually are similar. With a machine having such transfer vessel, the alloy in the transfer vessel is able to be discharged via an outlet port by pressurising an upper region of the vessel. From such discharge port, the alloy is able to be injected into the metal flow system as described above for the other machine types.

As indicated above, it is highly desirable that the alloy has a flow velocity at the outlet end of a CEP which is close to or within a preferred range of 50 to 80%, such as 65 to 75% of the flow velocity at the inlet end of the CEP. The flow velocities indicated are high relative to flow velocities used in high pressure die casting machines, particularly in the case of magnesium alloys. As the alloy flow velocity decreases as the alloy passes through the CEP, due to the CEP increasing in cross-section in the flow direction, the flow velocity at the inlet end of the CEP therefore needs to be even higher. The flow velocity of the alloy through the outlet end of the CEP preferably is 20 to 50% less, such as 25 to 35% less, than the flow velocity at or upstream of the inlet end of the CEP. In many instances, the outlet flow velocity may be about two-thirds of the flow velocity at or upstream of the inlet end such that, with an inlet flow velocity of about 150 m/s, the flow velocity at the outlet of the CEP is about 100 m/s. The machine with which the metal flow system is used needs to have an alloy output flow rate which is consistent with these requirements or, for a given machine, the metal flow system needs to have a CEP with inlet and outlet end cross-sectional areas which are consistent with attaining the required flow velocities for the CEP from the output flow velocity for the machine. Thus, for a machine providing a relatively low output flow rate, such as due to a low piston velocity, the inlet and outlet cross-sectional areas of the CEP will need to be small, resulting in an extended flow time.

With use of a metal flow system according to the present invention, having a CEP in which solidified alloy is able to exhibit a microstructure characterised by striations or bands resulting from alloy element separation, it is believed that the microstructure obtained in a resulting casting is unique. That

microstructure is broadly detailed above, in terms of it having fine primary particles in a matrix of secondary phase, with the primary particles less than 40 μm. The primary particles not only are small, frequently about 10 μm or less, but they also are evenly distributed. Moreover, the microstructure is able to be obtained substantially fully throughout a casting produced by the process of the present invention. A further more important factor is one which results from the alloy element separation which occurs in the CEP under the conditions which cause the alloy to achieve a semi-solid state possessing thixotropic properties. It is found that the microstructure of the casting reflects this separation in at least the primary particles of the casting, as with the primary particles in the striated or banded microstructure of alloy solidified in the CEP, as explained in the following.

With normal growth of primary particles, the core or first part to solidify is relatively rich in the primary element. As the dendrites grow, the concentration of a secondary element in the surrounding molten alloy accordingly increases, due to the removal of the primary element, while the concentration of the primary element in the surrounding melt decreases. Thus, the growing primary particles exhibit a graded ratio of primary to secondary element from its core or centre, with the primary element decreasing and the secondary element increasing in concentration. Thus, with a magnesium alloy containing aluminium, such as the alloy AZ91D, normal growth gives rise to primary particles which have a magnesium-rich core or centre but which, from the core or centre, have a decreasing magnesium content and an increasing aluminium content. However, the alloy element separation resulting from the CEP, in a metal flow system according to the present invention, gives rise to alloy element separation on the basis of density, and modification of the normal growth. This modification results in a fluctuating variation in alloy elements from the core or centre of the primary particles which, instead of being gradual and substantially uniform, is more of a fluctuating form such as a decaying sinusoidal form. Thus, while the core or centre is richer in the primary element and relatively low in the secondary element, the secondary element first rises, then falls and thereafter can rise again in directions outwardly from the core or centre. Thus, with a magnesium alloy such as AZ91D, the primary particles are low in aluminium at the core or centre but, from there, the aluminium content initially increase

relative to magnesium over about an initial third of the radius of the particles, then decrease relative to magnesium over about the second third of the radius, and thereafter increase again to the outer perimeter of the particles. This modification occurs in the CEP, and is able to be retained in primary particles with flow of the alloy into the die cavity.

The fluctuating ratio of primary and secondary alloy elements in the primary particles results from the conditions generated by the CEP. Computer simulations of flow conditions through a CEP generating a striated or banded microstructure indicate that, with flow of alloy through a suitable form of CEP which achieves the indicated flow rates through the outlet of the CEP, intense pressure waves are generated in the alloy. The simulations indicate that the pressure waves are at a level of about ±400 MPa. It is known that pressure differences of the order of a few 100 kPa can cause separation of less and more dense elements of an alloy, such as magnesium and aluminium. The computer simulations therefore point to pronounced separation, with movement of a less dense element to high pressure pulses and of a higher density element to low pressure pulses. Moreover, the computer simulations suggest that the intense pressure waves will have a wavelength of the order of 40 μm for a magnesium alloy. This is found to accord very closely with results achieved in practice. As indicated above, it is found that, for alloy solidified in a CEP under conditions providing for relatively rapid solidification in a die cavity, and back into the CEP, the resultant striations or bands in the microstructure of alloy solidified in the CEP have a wavelength of the order of 40 μm. That is, the spacing between centres for successive like bands, of primary element or secondary element, is of the order of 40 μm. For aluminium and other alloys, the spacing more usually is of the order of about 200 μm.

Reference now is directed to the accompanying drawings, in which:

Figure 1 is a photomicrograph illustrating a typical microstructure obtained substantially fully throughout a casting of a magnesium alloy, produced using a metal flow system according to the present invention;

Figure 2 is a photomicrograph illustrating a typical microstructure obtained in the CEP used in the system in which the casting illustrated in Figure 1 was produced;

Figures 3 and 4 are a photomicrograph illustrating an aluminium alloy obtained in the CEP used in the system in which the casting illustrated in Figure 1 was produced.

Figure 1 is a photomicrograph illustrating a typical microstructure of a casting produced with use of the present invention, from AZ91 magnesium alloy. This microstructure shows primary particles in the form of fine, rounded or spheroidal, or degenerate dendrite, cells substantially less than 10 μm in size and occupying up to 60% of the volume fraction. Each primary particle contains concentration rings showing a fluctuating, sometimes somewhat decaying sinusoidal, ratio of constituent alloy elements. Between the primary particles, there is solidified metal of eutectic composition, with the fineness of the eutectic structure difficult to resolve despite the level of magnification used.

Figure 2 is a photomicrograph of the microstructure of AZ91 magnesium alloy solidified in a CEP, in producing a casting such as illustrated in Figure 1. The direction of alloy flow through the CEP is shown by an arrow. The photomicrograph shows banding or striations extending transversely with respect to the flow direction. While not very readily discernible in this instance, the bands or striations as shown by X-ray analysis using secondary electron microscopy result from segregation of the parent metal magnesium and alloy additive elements such as aluminium. This segregation is believed to occur due to intense pressure waves generated in the CEP by the reduction in alloy flow velocity as it flows through the CEP. The dynamic environment provided by the pressure waves is believed to lead to nucleation of primary particles of the parent metal at relatively high temperatures. Alternate bands are found to have a higher percentage of parent metal and a higher solidification temperature than would be expected for the starting alloy, relative to primary particles obtained in sprue/runner metal obtained by conventional pressure die casting. Similarly, the secondary phase rich intervening bands have a higher percentage of alloy elements and a lower solidification temperature than expected for the alloy, relative to secondary phases obtained in sprue/runner metal of conventional die casting. The microstructure is characterised by fine primary particles substantially smaller than 10 μm in a secondary phase matrix, with a banding wavelength of about 40 μm.

Figure 3 is a photomicrograph illustrating a typical microstructure of a casting produced with use of the present invention, from CA313 aluminium alloy. This shows fine, rounded or spheroidal, or degenerate dendrite primary particles less than 40 μm in size, with many as small as about 10 μm and finer, in a matrix of very fine secondary eutectic phase. The microstructure also shows a few larger spheroidal primary particles, but essentially all less than about 60 μm, which formed in the shot sleeve of the cold-chamber die casting machine used. That is, those larger particles formed before injection through the CEP and into the die cavity, and thus were carried into the die cavity.

Figure 4 is a photomicrograph of the microstructure of CA313 aluminium alloy which solidifies in a CEP in producing a casting such as illustrated in Figure 3. The direction of alloy flow through the CEP again is shown by an arrow. The microstructure shows banding or striations extending transversely with respect to the flow direction. The microstructure overall is similar to that of Figure 2, except that the primary particles are of the parent metal aluminium, rather than magnesium, while the banding or striations are more evident and the darker bands richer in secondary phase eutectic show a band wavelength of about 200 μm. Successive secondary phase darker bands are highlighted by an array of parallel arrows extending transversely with respect to the flow direction.

In addition to matters detailed above, the metal flow system of the present invention enables the production of quality castings of a wide range of suitable alloys, which have a number of practical benefits. These include low levels of porosity, good surface finish, low levels of cast metal needing to be recycled, and the production of castings of a wide range of wall thicknesses.

In relation to porosity, the modification of alloy flow produced by the CEP of a metal flow system according to the present invention achieves filling of a die cavity by alloy flow which differs from that obtained in conventional high pressure die casting. Thus, in achieving a semi-solid state possessing thixotropic properties, the alloy flow in the die cavity progresses away from the inlet to the die cavity as a semi-solid front, rather than as a jet which issues from a gate in conventional die casting arrangements to a remote region of the die cavity. The semi-solid front progresses to remote regions of the die cavity, in a manner which varies with the form of the die cavity, to achieve filling of all

regions. This difference in flow gives rise to flow which is substantially less prone to entrain gas and, hence, provides castings which are able to be substantially free of pores or in which pores are small and more uniformly dispersed. This form of flow is described in PCT/AU98/00987 (WO00/28065) for magnesium alloys. However, contrary to the distinction drawn in that application between those alloys and alloys of zinc and aluminium, it is found that, with the metal flow system of the present invention, similar alloy flow and resultant low levels of porosity are able to be achieved in all suitable alloys.

Low levels of porosity, of course, are of significant practical benefit in terms of casting quality. However, it is found that the alloy flow which enables those low levels also has another practical benefit in terms of low levels of alloy which need to be recycled. It is indicated above that some characteristics of the microstructure able to be achieved in castings produced with use of the present invention can be obtained in some regions of castings produced by conventional hot chamber die casting where large overflows are used. The flow of alloy in the die cavity achieved with use of the present invention generally enables the use of any overflows to be avoided, unless they are required to be provided for ejection purposes. That is, there generally is no need for overflows at all and, even where they are appropriate, they are able to be kept to a minimum in which overflow metal amounts to only a small proportion of the weight of alloy supplied to the die cavity. Indeed, it generally is only with castings of a form in which alloy flow in the die cavity proceeds on two fronts which join together that an overflow is likely to be necessary, since a pocket of gas otherwise can be trapped between the fronts. However, to avoid such gas pocket, only a small overflow to enable venting of the gas is likely to suffice.

Some need to recycle metal does result from alloy which solidifies back from the die cavity, along the flow path and into the CEP. However, relative to the weight of metal which similarly results in other casting processes discussed herein, that weight of metal can be very small. Thus, while those other processes typical result in runner/sprue metal in excess of 50% of the weight of a casting, and in some cases in excess of 100% of the casting weight, the present invention enables use of a metal flow path which generally gives rise to metal solidified therein which is substantially less than 30% of the casting weight, and frequently less than 5% of that weight.

The low porosity of castings able to be produced by the present invention also has benefits for the surface finish of resultant castings. That is, the attainment of a good surface finish, substantially free of pores, is facilitated. This is of particular benefit with magnesium alloys, as detailed in PCT/AU98/00987 (WO99/28065).

A further practical importance of the invention is that it enables the production of castings of thick wall sections, of very thin wall sections and combinations of thick and very thin wall sections. The wall thickness can be from about 0.5 mm upwards. Parts thinner than 0.5 mm can be cast, but shape and length may be limiting factors.

It is indicated above that the microstructure able to be obtained in castings produced by use of the present inventions is an optimum for at least some applications. This applies where the physical properties required in the casting are enhanced by the avoidance of the normal dendrite form of the primary phase and the very fine, uniform particle size of the microstructure. Due to these factors, the castings have good strength characteristics. However, the properties are able to be further enhanced or modified, by subjecting the casting to a suitable tempering or ageing heat treatment.

Finally, it is to be understood that various alterations, modifications and/or additions may be introduced into the constructions and arrangements of parts previously described without departing from the spirit or ambit of the invention.

CLAIMS:

1. A metal flow system, for use in pressure casting of an alloy, using a pressure casting machine having a source of supply of molten alloy, wherein the system includes a mould or die tool component which defines at least part of a flow path into which molten alloy is receivable from the source of supply and along which alloy is able to flow for injection into a die cavity defined by a mould or die; the mould or die tool component defines, as part of the flow path, a controlled expansion port (a CEP) which, from an inlet end to an outlet end of the CEP, increases in cross-sectional area whereby the state of alloy in its flow through the CEP is able to be modified from a molten state to achieve a semi-solid state possessing thixotropic properties and to enable the alloy in that state to flow into the die cavity; and wherein the CEP has a form such that, with solidification of alloy in the die cavity and back along the flow path into the CEP, to provide a resultant casting having a microstructure characterised by fine, degenerate dendrite, or rounded or spheroidal, primary particles in a matrix of secondary phase, alloy solidified in the CEP has a microstructure characterised by striations or bands extending transversely with respect to the alloy flow therethrough, with the bands resulting from alloy element separation, and with alternate bands relatively richer in respective elements and respectively in primary and secondary phases.

2. The metal flow system of claim 1, wherein the system is adapted for heat energy extraction from the mould or die tool component whereby solidification of alloy in the CEP is facilitated on completion of a moulding cycle and solidification of alloy in the die cavity back along the flow path to the CEP.

3. The metal flow system of claim 2, wherein the system is adapted such that said heat energy extraction is limited upstream of the inlet end of the CEP, with respect to the alloy flow direction whereby, on solidification of alloy in the CEP, a solid-liquid interface is established at or a short distance downstream from the inlet end of the CEP.

4. The metal flow system of any one of claims 1 to 3, wherein the increase in cross-sectional area of the CEP provides an alloy flow velocity at the outlet end of the CEP which is from 50 to 80% of the alloy flow velocity at the inlet end of the CEP.

5. The metal flow system of any one of claims 1 to 3, wherein the increase in cross-sectional area of the CEP provides an alloy flow velocity at the outlet end of the CEP which is from 65 to 75% of the alloy flow velocity at the inlet end of the CEP.

6. The metal flow system of any one of claims 1 to 5 for use in the production of castings of a magnesium alloy in a pressure casting machine, wherein CEP is adapted to provide a magnesium alloy flow velocity at the inlet end of the CEP which is in excess of 60 m/s.

7. The metal flow system of claim 6, wherein the CEP is adapted to provide a magnesium alloy flow velocity at the inlet end of the CEP of from 140 to 165 m/s.

8. The metal flow system of any one of claims 1 to 5, for use in production of castings in a pressure casting machine from a selected alloy other than a magnesium alloy, wherein the CEP is adapted to provide a selected alloy flow velocity at the inlet end of the CEP which is in excess of 40 m/s.

9. The metal flow system of claim 8, wherein the CEP is adapted to provide a selected alloy flow velocity at the inlet end of the CEP of from 80 to 120 m/s.

10. The metal flow system of any one of claims 1 to 9, wherein the CEP has a length of from 5 to 40 mm.

11. The metal flow system of claim 10, wherein the CEP has a length of from 5 to 20 mm.

12. The metal flow system of claim 10, wherein the CEP has a length of from 10 to 15 mm.

13. The metal flow system of any one of claims 1 to 12, wherein the CEP is of annular cross-section.

14. The metal flow system of any one of claims 1 to 12, wherein the CEP is of rectangular cross-section.

15. A process for producing an article by high pressure casting, wherein molten alloy is supplied under pressure to metal flow system for flow along a flow path defined by the system to a die cavity defined by a mould or die; the flow path is defined at least in part by a mould or die tool component; and wherein the component is formed to define, as part of the flow path, a controlled expansion point (a CEP) which, from an inlet end to an outlet end of the CEP, increases in cross-sectional area whereby the state of the alloy in its flow through the CEP is modified from a molten state to achieve a semi-solid state possessing thixotropic properties and to cause the alloy to flow in that state into the die cavity; the form of the CEP being provided such that, with solidification of the alloy in the die cavity and back along the flow path into the CEP, to provide a resultant casting having a microstructure characterised by fine degenerate dendrite, or rounded or spheroidal, primary particles in a matrix of secondary phase, alloy solidified in the CEP has a microstructure characterised by striations or bands extending transversely with respect to alloy flow therethrough, with the bands resulting from alloy element separation, and with alternate bands relatively richer in respective elements and respectively in primary and secondary phases.

16. The process of claim 15, wherein heat energy is extracted from the mould or die tool component whereby solidification of alloy in the CEP is facilitated on completion of a moulding cycle and solidification of alloy in the die cavity back along the flow path to the CEP.

17. The process of claim 16, wherein said heat energy extraction is limited upstream of the inlet end of the CEP, with respect to the alloy flow direction whereby, on solidification of alloy in the CEP, a solid-liquid interface is established at or a short distance downstream from the inlet end of the CEP.

18. The process of any one of claims 15 to 17, wherein the increase in cross-sectional area of the CEP provides an alloy flow velocity at the outlet end of the CEP which is from 50 to 80% of the alloy flow velocity at the inlet end of the CEP.

19. The process of any one of claims 15 to 17, wherein the increase in cross-sectional area of the CEP provides an alloy flow velocity at the outlet end of the CEP which is from 65 to 75% of the alloy flow velocity at the inlet end of the CEP.

20. The process of any one of claims 15 to 19, for use in the production of castings of a magnesium alloy in a pressure casting machine, wherein CEP provides a magnesium alloy flow velocity at the inlet end of the CEP which is in excess of 60 m/s.

21. The process of claim 20, wherein the CEP is adapted to provide a magnesium alloy flow velocity at the inlet end of the CEP of from 140 to 165 m/s.

22. The process of any one of claims 15 to 19, for use in production of castings in a pressure casting machine from a selected alloy other than a magnesium alloy, wherein the CEP provides a selected alloy flow velocity at the inlet end of the CEP which is in excess of 40 m/s.

23. The process of claim 22, wherein the CEP provides a selected alloy flow velocity at the inlet end of the CEP of from 80 to 120 m/s.

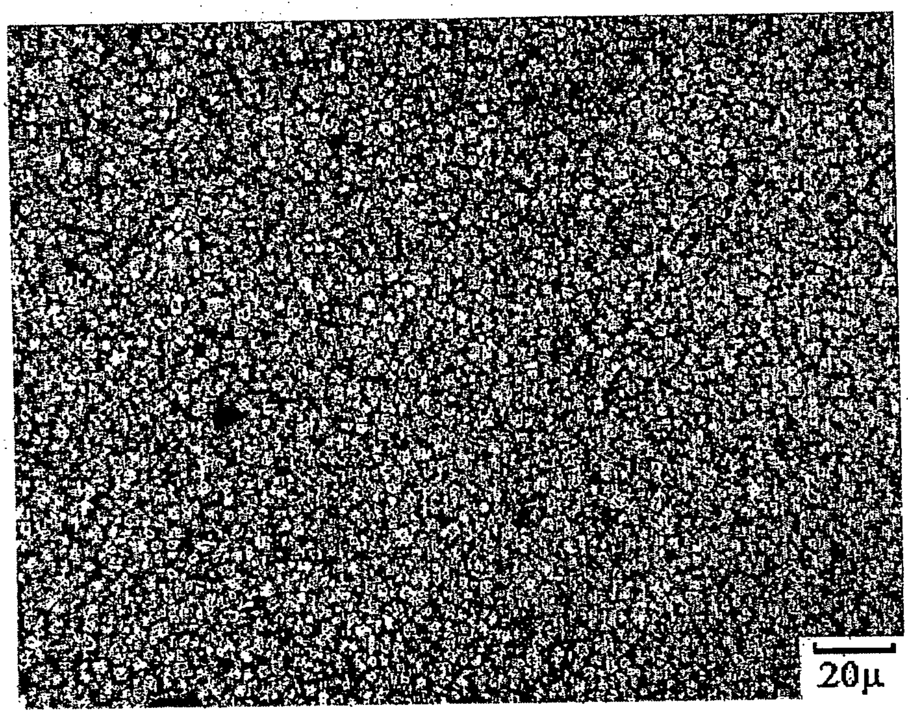

FIG 1

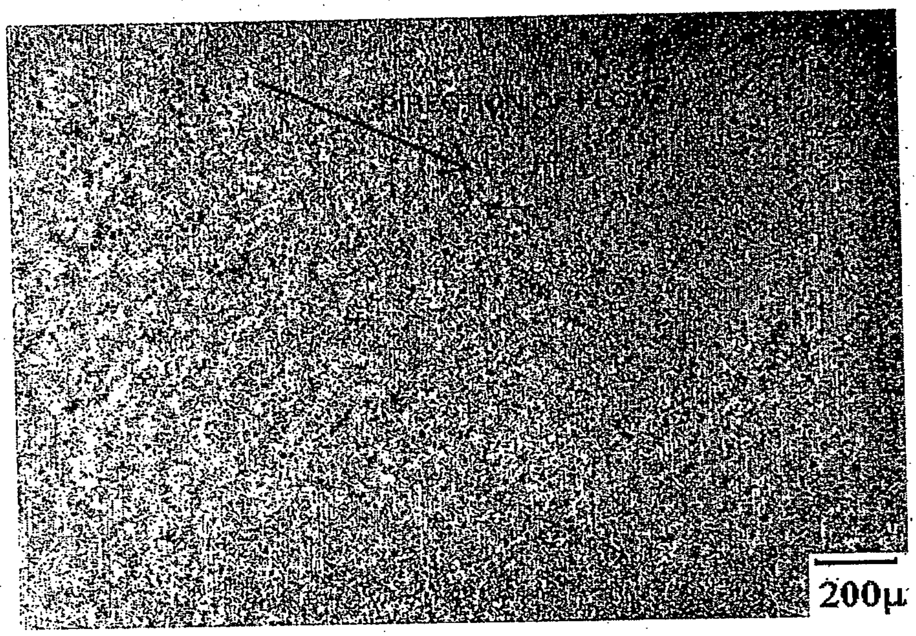

FIG 2

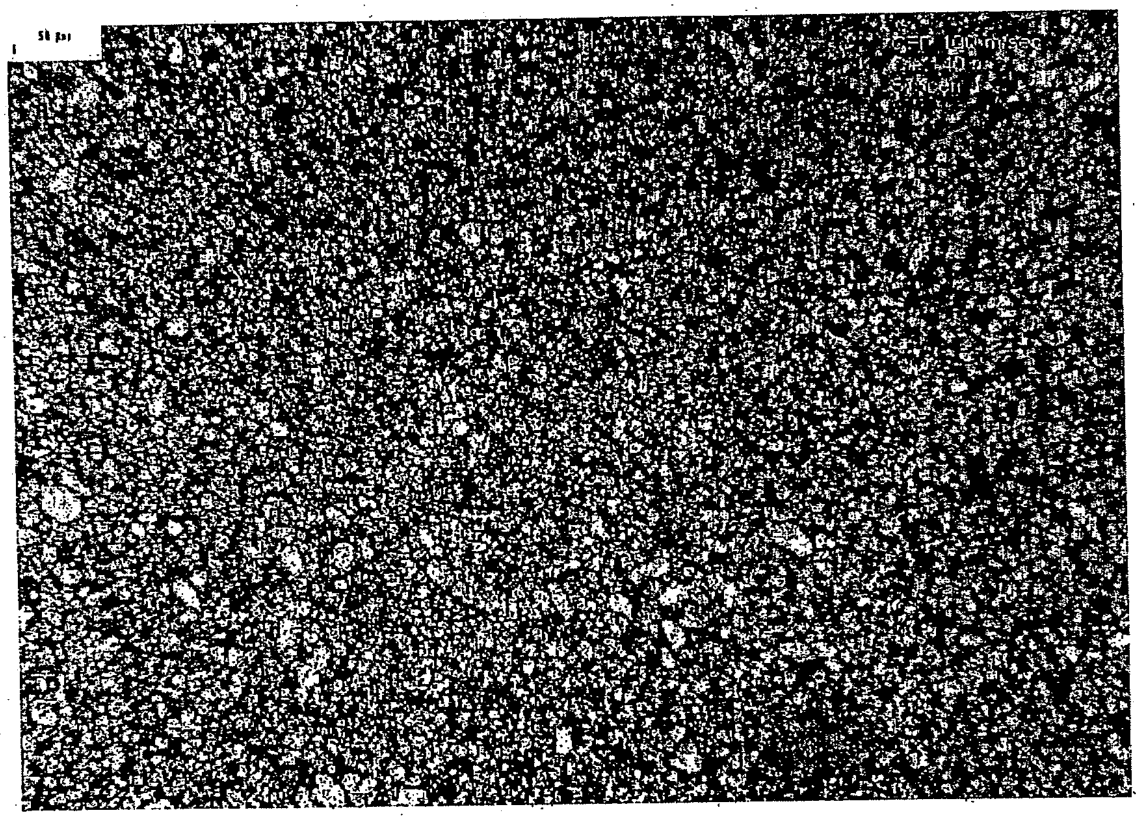

FIG 3

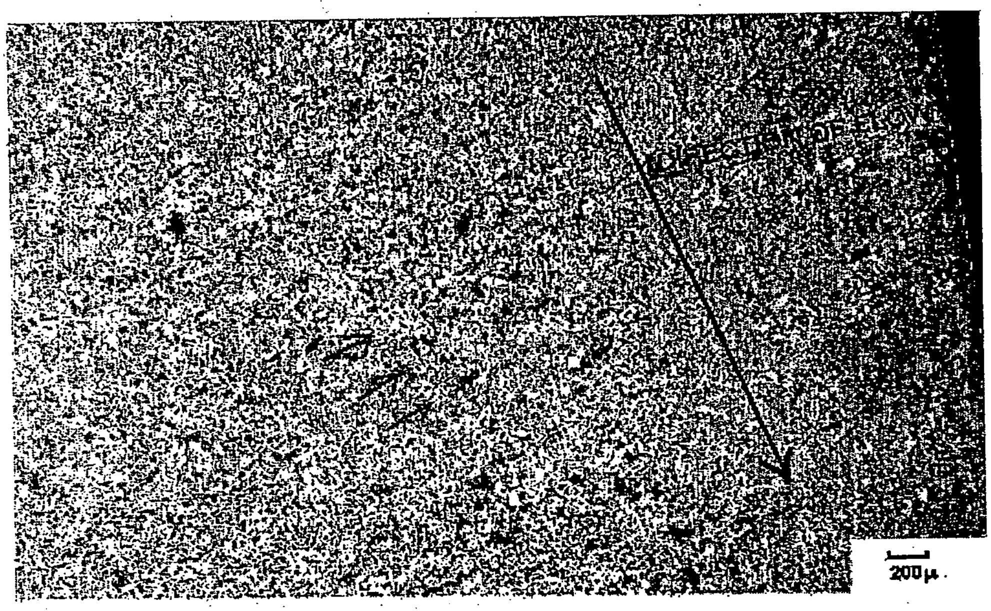

FIG 4

INTERNATIONAL SEARCH REPORT

International application No.
PCT/AU02/01139

A. CLASSIFICATION OF SUBJECT MATTER

Int. Cl. 7: B22D 17/20

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC7 as above and B22D 17/00, 17/02, 17/04, 17/06, 17/08, 17/10, 17/12

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
Derwent WPAT: IPC7 as above and B22D 17/00, 17/02, 17/04, 17/06, 17/08, 17/10, 17/12 and (expan+ or taper+ or section+)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
P, X	WO 2002/30596 A1 (C. S. I. R. O.) 18 April 2002 Whole Document	1 to 23
P, X	WO 2002/16062 A1 (C. S. I. R. O.) 28 February 2002 Whole Document	1 to 23
A	WO 1995/34393 A1 (Cornell Research Foundation) 21 December 1995 Whole Document	

☐ Further documents are listed in the continuation of Box C

☒ See patent family annex

* Special categories of cited documents:

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier application or patent but published on or after the international filing date

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"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
20 September 2002	27 SEP 2002

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This Annex lists the known "A" publication level patent family members relating to the patent documents cited in the above-mentioned international search report. The Australian Patent Office is in no way liable for these particulars which are merely given for the purpose of information.

Patent Document Cited in Search Report		Patent Family Member			
WO	200230596	AU	20000763	AU	200195269
WO	200216062	AU	20009678	AU	200181596
WO	9534393	EP	765198	US	5501266

END OF ANNEX